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# Chronic Dredging on the Upper Mississippi River Remedied with Innovative River Training Structures

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**ABSTRACT**

The St. Louis District of the U.S. Army Corps of Engineers has recently constructed a set of innovative river training structures in the Upper Mississippi River to remedy a repetitive maintenance dredging problem. The reach of river known as Bolters Bar had required dredging almost every year since the construction of Lock and Dam 26 in the 1930's. A set of traditional dikes or wingdams could have reduced dredging and met the needs of the towing industry. However, the state resource agencies and recreational boaters would have resisted the construction of these structures in this complex reach of river. The reach required the development of a unique solution to meet the objectives of the numerous user groups and agencies involved.

The Corps of Engineers studied the river utilizing a novel, small-scale, movable riverbed modeling approach. The model was used to test design solutions and discuss numerous proposals with towboat pilots and natural resource specialists. The team members agreed upon a design that incorporated 4 unique river training structures, called blunt-nosed chevrons, which would meet the needs of all those involved. These "U" shaped structures were originally conceived by engineers in the St. Louis District in the early 1990's for the purpose of protecting dredge disposal areas from river currents. After the first three chevrons were constructed in Pool 24 in 1993, biologists began to realize their significant benefits to aquatic habitat. It was also realized that the isolated dredge disposal sand islands in the downstream shadow of each structure were being utilized by the public for day use and camping purposes.

The Bolters Bar reach enabled engineers to utilize these multi-purpose structures for one additional purpose, channel improvement. The chevrons were constructed in the spring of 2002. During the following low water season, the reach did not require dredging. Hydrographic survey data revealed an increase in depth in the navigation channel and an improved alignment for tows. Areas where there usually was less than 3 meters (10 feet) of water, there now are at least 4.5 meters (15 feet) of depth. Although these particular

structures have not yet been fully evaluated for their ecological benefits, past experience with the original chevrons indicate that a vast amount of aquatic diversity will eventually be created at each of these structures.

Engineers are increasingly looking toward innovative solutions to solve traditional river engineering problems while also protecting the riverine environment. Chevrons, as well as other environmental river training structures, will continue to be utilized to resolve many of the problems that challenge river engineers and their partnering agencies.

## BACKGROUND

The Bolters Bar / Iowa Island reach is located on the Upper Mississippi River approximately 45 River Miles (72 kilometers) upstream of St. Louis, Missouri. The reach is near the mid point of the navigation pool established by the Mel Price Locks and Dam at Upper Mississippi River Mile (UMRM) 200 near Alton, Illinois. The area is just upstream of the Upper Mississippi River's confluence with the Illinois River. This reach of river is used heavily by commercial navigation tows and is part of a crucial link between the Upper and Lower Mississippi Rivers. Figure 1 is a vicinity map of the area and Figure 2 shows an aerial photograph of the reach.

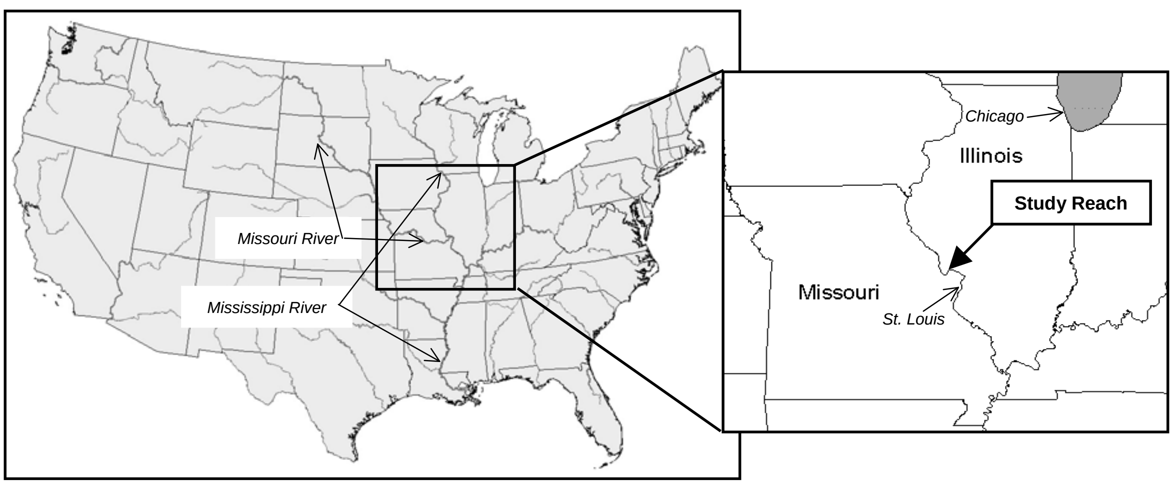


**Figure 1: Project Vicinity Map.**

The river at this location is divided into as many as four separate channels as the river enters a slight bend near UMRM 226. The main navigation channel is along the Illinois bank while the environmentally sensitive side channels are all along the Missouri side of the river. The first side channel, Dardenne Chute, begins near UMRM 228.5 and extends behind Dardenne Island. The second side channel, Bolter Chute, begins near UMRM 227.3, extends behind Bolter Island, and merges with Dardenne Chute near UMRM 226.0. The third side channel, Iowa Chute, begins at the head of Iowa Island near UMRM 225.0, extends behind Iowa Island and merges with Dardenne / Bolter Chute near UMRM 224.0. The large, single side channel merges with the main channel near UMRM 221.5.

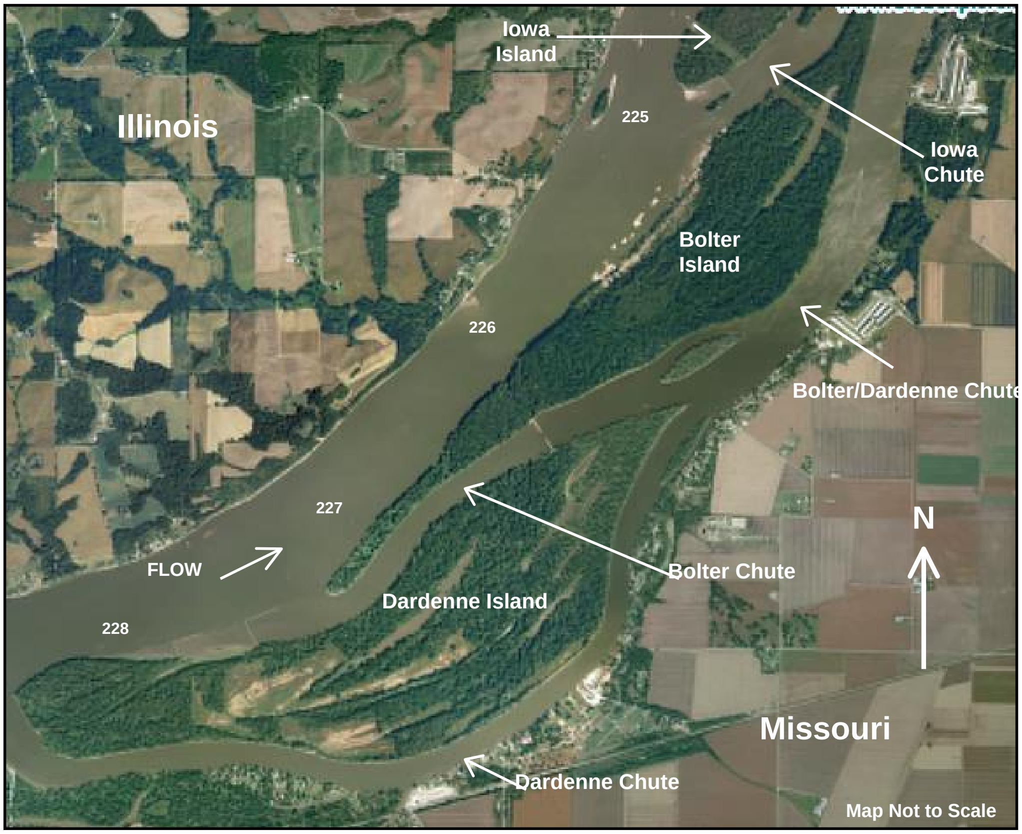


**Figure 2: Aerial Photograph of the Project Reach.**

The river is in close proximity to the populous metropolitan area of St. Louis, Missouri and one of the fastest growing counties in the U.S. Numerous marinas for recreational boaters are located within these side channels and on the floodplain along the Missouri banks. The area contains one of the densest concentrations of marinas and boats along the entire Mississippi River. In the summer months, thousands of boaters recreate in these side channels and utilize them as links to the main channel.

## PROBLEM DESCRIPTION

The Corps of Engineers, as authorized by Congress, is responsible for maintaining a navigable channel at least 2.7 meters (9 feet) deep by 91 meters (300 feet) wide on the Upper Mississippi River through the use of river training structures, dredging operations, and water level management at the lock and dams. This reach of river had required annual dredging usually once or twice a year due to depths that did not meet the minimum requirements at times of low water. In most years, dredging was needed during the typical low water season, which unfortunately coincided with the fall harvest and the busiest period for shipping agricultural products down the Mississippi River for export. In many years, tows would start bumping the river bottom before a dredge could be mobilized. As such, the navigation industry was extremely concerned with frequency of dredging in this area. The reach was also considered to be a major safety concern to the industry.  Groundings and/or break-ups were always a possibility, which could close the river down for days for cleanup during crucial shipping periods.

Towboat pilots also expressed their concerns about problems navigating downbound past Iowa Island.  To navigate the reach safely, they were required to zigzag and maneuver sideways to the river channel to travel past the island.  The pilots were not only interested in solving the dredging problem, but were also interested in establishing a better alignment that would allow them to navigate in a straighter path to pass Iowa Island.

Solutions to these problems were difficult to design due to the recreational interests combined with increasing environmental awareness about side channels.  These competing interests made this reach extremely sensitive to any sort of change.  Therefore, equal consideration was given to all these interests as remedial measures were being considered to minimize any negative effect on people and the environment.

**Dredging Analysis**

In terms of dredging frequency and groundings, this reach has been one of the most troublesome within the three navigation pools in the St. Louis District.  Figure 3 shows the areas that have required dredging from 1980 through 2001 between UMRM 228 and 224.  One of the regularly dredged areas was located near the head of Bolter Island at UMRM 227.  However, the most costly and the most frequently dredged area was just upstream the head of Iowa Island between UMRM 226 and 225 where the configuration and width of the river caused almost annual shoaling and dredging.

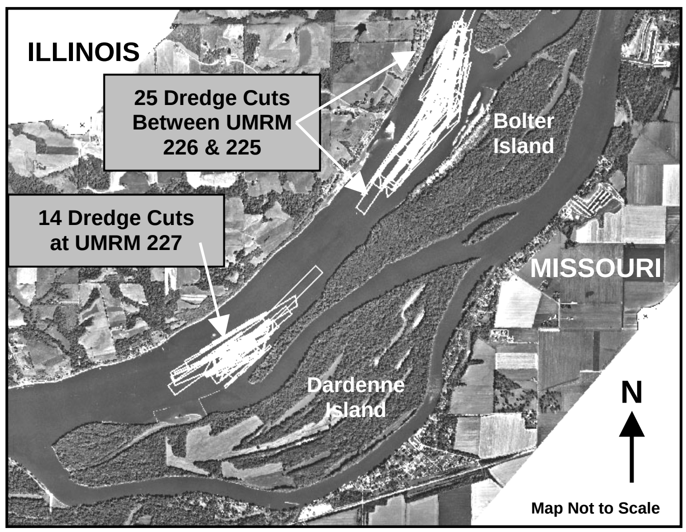


**Figure 3:  Dredge Cut Locations, 1980 to 2001.**

The Corps of Engineers uses two types of hydraulic pipeline dredges for dredging operations on the Mississippi River.  The Dustpan Dredge was designed by the Corps of Engineers as an efficient means of removing the large volumes of sandy material that typically accumulate in problem areas along the Mississippi River.  This dredge uses water jets at the end of a wide suction head to agitate the sand into a slurry which is then pumped up into the dredge and pipelined a short distance outside of the navigation channel. The Cutterhead Dredge uses an active rotating auger at the end of the suction line.  Although this dredge is much less efficient, the material can be discharged up to 915 meters (3000 feet) away or almost 4 times as far as a Dustpan Dredge.  Depending upon availability and disposal requirements, both types of dredges have been used in this reach.

Figure 4 shows a graph of the yearly dredging totals from 1980 to 2001 between UMRM 226 and 225. Within this 1.6-kilometer (1-mile) reach, over 4.2 million cubic meters (5.5 million cubic yards) of material were dredged at a cost of over $6.1 million over a period of 22 years.

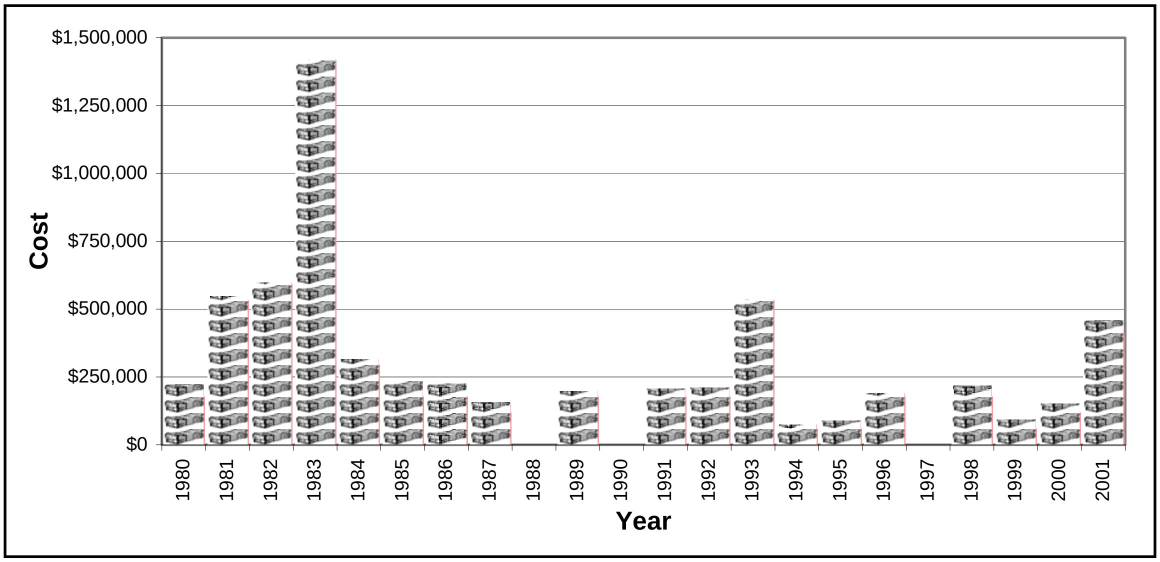


**Figure 4: Annual Dredging Cost, UMRM 226 to 225 – 1980 to 2001.**

Dredging in this area has not only been repetitive and costly, but also has been troublesome from a disposal standpoint. The normal disposal method of dredge material in the St. Louis District has been open water placement without confinement. Areas to place this material within the river channel had been limited. The Corps of Engineers had experienced difficultly locating viable dredge disposal placement areas that would not negatively impact recreation, homeowners, or the environment.

The property owners of numerous homes located along the Illinois bankline objected to any plans to place additional dredge material near their bankline. They reported that boating was becoming more difficult along their banks due to shallow conditions and were requesting Corps of Engineers assistance in maintaining their access to the river. Biologists and recreational boaters from Missouri were opposed to placing dredge material along Bolter Island, fearing that the material may accumulate in the entrance to Iowa Chute.

In 1996, under the Avoid and Minimize Environmental Impacts Program, the Corps of Engineers experimented with placing dredge material in deep portions of the channel thalweg. Physical and biological monitoring showed no adverse effects to the environment but the deep portion of channel could only handle a small portion of the overall volume dredged from the reach. Furthermore, this material was eventually naturally transported from these deep areas and was probably deposited in other problem areas just downstream that also experience repetitive channel maintenance dredging. Therefore, the Corps of Engineers investigated designs that may reduce the shoaling problem and utilize the remaining dredge material in a beneficial manner.

## Flow Distribution

One of historic causes of the repetitive dredging through the reach was the loss of flow in the main channel to the side channels. Figures 5 and 6 show flow distribution measurements collected at UMRM 227.3 and 224.6 between 1988 and 1997. Each shaded bar shows the percent of the total flow contained by each channel from 1988 to 1997.

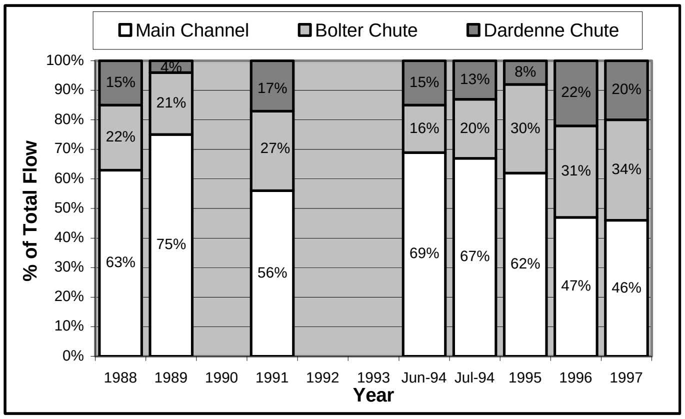


**Figure 5: Flow Distribution at UMRM 227.3.**

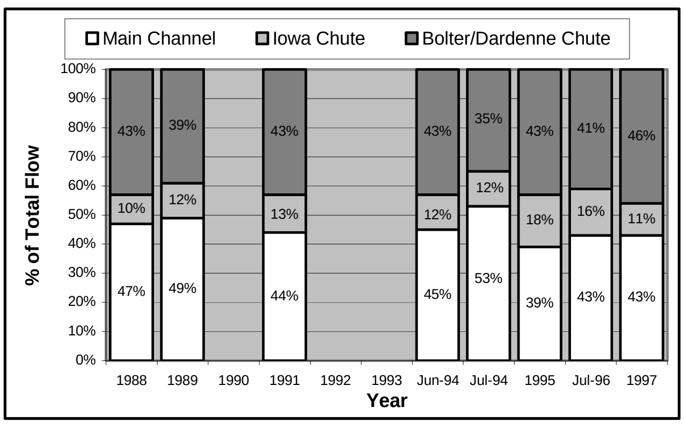


**Figure 6: Flow Distribution at UMRM 224.6.**

At UMRM 227.3, historical discharge measurements show that the flow in the main channel near the head of Bolter Island had averaged just 65% of the total flow up until 1995. More recent measurements revealed steady flow decreases in the main channel. In 1996 and 1997 the flow in the main channel had dropped to almost 45% of the total. The decrease in flow in the main channel correlated with increased flow in both Bolter and Dardenne Chutes.

At UMRM 224.6, just downstream of the head of Iowa Island, the data showed the main channel carried nearly 50% of the total flow from 1988 to 1994. From 1995 to 1997, the flow in the main channel dropped to almost 40% of the total flow. The flow in both Iowa Chute and Bolter/Dardenne Chute increased slightly.

An increase in flows through Bolter Chute appeared to be the main cause for the reduction of flow in the main channel. A site inspection revealed that portions of a dilapidated, wooden-pile, closure structure in the side channel near UMRM 226.3 appeared to have deteriorated, probably during the great floods of 1993 and 1995. Historically, these floods rank as the first and third largest on the Upper Mississippi River in St. Louis. The banklines near the structure were eroding rapidly, an increase in velocity was apparent, and the flanking of the structure appeared imminent. It was concluded that the flow equilibrium originally established with this structure was altered when the wooden piles began to deteriorate.

**Navigation Alignment**

Another possible cause of the repetitive dredging was the alignment of the main channel with the islands and side channels. A bend in the river located near the head of Bolter Island formed a point bar that extended from the Illinois bankline. This alignment coupled with the loss of flow into Bolter Chute caused the point bar to encroach upon the main channel, which narrowed the channel and contributed to the dredging problem near UMRM 227.

The other alignment problem was at the downbound approach toward Iowa Island. The flow of the river was directed towards the head of this island located in the middle of the channel. The channel width just upstream of the island was another cause of the dredging problem. Near UMRM 226, where dredging had not been an issue, the width of the river was 460 meters (1,500 feet) with depths greater than 6 meters (20 feet). However, near UMRM 225.3 in the middle of the typical shoaling area, the width of the river was over 760 meters (2,500 feet) with depths less than 3 meters (10 feet). The excessive width of the main channel between UMRM 226 and 225 induced lower velocities which allowed for more sediment deposition. This combination of poor alignment, increased width in the main channel, and the loss of flow to Iowa and Bolter Chutes were the main factors responsible for the repetitive dredging between UMRM 226 and 225.

## PURPOSE AND GOALS

The conventional solution to the problems would have been the construction of rock closure structures across the mouths of each of the side channels. This measure would have distributed additional flow in the main channel at the expense of the side channels. The increased flow would have created beneficial velocities, decreased deposition, and deepened the main channel. However, closing off the side channels would have adversely affected the river environment, aquatic habitat, and the thousands of recreational boaters who utilize the side channels to enter the main channel. Therefore, the environmental and recreational interests for the side channels eliminated this type of solution.

The Corps of Engineers set forth on a study to assess the sediment transport conditions of the Mississippi River and to examine the interaction between the main channel and the side channel complex. The primary goal was to evaluate designs that would reduce and/or eliminate the repetitive channel maintenance dredging situation without damaging the environment or creating problems for recreational boaters.

With a multitude of interests involved, the Corps of Engineers required a team approach to find a synergistic solution to the problem. It was important to involve the navigation industry, environmentalists and state and federal conservation and wildlife officials to help devise a plan to reduce the need for dredging in the Bolters Bar Reach. The team wanted an innovative solution that would not only reduce or eliminate dredging but also allow the side channels to remain relatively unchanged. This included an examination of methods to modify velocities in the main channel and improve the navigation channel alignment without closing off the side channels. The Corps of Engineers needed to consider the use of both conventional and unconventional structures. Assessments of these alternatives were to include the examination of the ultimate effects to sedimentation patterns within the main channel, at the entrances to the side channels, and within each side channel.

To accomplish assessments of multiple designs, a small-scale physical movable bed model (micro model) was used. The micro model not only allowed engineers to test numerous design alternatives in a detailed manner but also allowed for the involvement of the Corps of Engineers' partners during the design conception phase. This process ensured that all those involved in the project agreed upon the final design.

## THE MODEL

The Corps of Engineers utilizes micro modeling technology for both plan formulation and to finalize design parameters. These physical hydraulic models of a river or stream utilize small scales with movable riverbeds and distorted scales. The Corps of Engineers developed this technology in 1993 from experience gained from the larger movable bed models that were commonly used in the past to qualitatively analyze changes in riverbed patterns. Although valuable, the cost to build and operate these large models was no longer feasible as budgets for projects continued to dwindle. The Corps of Engineers continues to refine this modeling technique to meet its own needs as well as those of their partners.

### Micro Modeling Methodology

Like the larger models, the micro model uses empirical techniques to replicate the trends of the riverbed. The models have been useful for the study of sediment distribution and riverbed pattern development within a river channel. This includes the general location of bars or depositional areas, scour holes, and the channel thalweg. The modeling methods allow for the qualitative prediction of riverbed patterns when applying a structure in the river channel. For example, the locations of scour and sediment deposition are desired in most inland waterways when a river training structure is implemented to solve a chronic dredging problem.

The fundamental theory behind movable bed modeling techniques is that smaller streams display similar tendencies of sediment transport and riverbed formations as compared to larger rivers. Therefore, large and small-scale models can be designed to simulate the tendencies of the prototype. John Franco, long considered an expert in movable bed modeling states, "In actuality, models of rivers are small rivers patterned after larger rivers and adjusted to reproduce the characteristics of the large rivers." In the late 1800's, Osborne Reynolds, an acclaimed scholar in hydraulics, had proved the validity of this thesis by using an extremely small-scale model of an estuary.

In 1887, Reynolds submitted a report to the British Association entitled "On Certain Laws Relating to the Regime of Rivers and Estuaries, and on the Possibility of

Experiments on a Small Scale." In this report he described an experiment by which he constructed a small-scale physical model of the estuary of the Mersey River in England. Reynold's model was approximately 2 meters (6.6 feet) in length, was built to a horizontal scale of 1:31,800 (5.1 cm = 1.6 km / 2 inches = 1 mile), a vertical scale of 1:960 (2.5 cm = 24.4 m / 1 inch = 80 feet), had a distortion of 1:33.1, and was composed of a zinc lined flume covered with sand. By contrast, micro models used today typically utilize horizontal scales between 1:3,600 and 1:14,000, vertical scales between 1:240 and 1:1200, and distortions between 1:6 and 1:20. Although Reynolds relaxed the laws of similitude, he was surprised to learn how well the model imitated the movement of sediment as compared to the prototype. He concluded that the model produced a bed configuration remarkably similar to that of the prototype, even though the model scales were drastically distorted and the model was extremely small-scale.

Fundamentally, all physical sediment transport models must relax or deviate from the laws of similitude. Yalin theorizes that if all the laws of similitude were followed, than a model cannot operate with the same fluid (water) as the prototype. He goes on to state that due to operational, technical, and economical restrictions, the modeler is compelled to use water in the model. The variance to similitude is also necessary to achieve the physical movement of sediment in the models. Among others, the sediment size, flow rates, and velocities are not directly scalable. Larger sediment must be used because the sand transported by the river is impossible to dimensionally scale for model purposes. Franco states, "In natural streams, the size of bed material does not vary in direct proportion to the size of the river and tends to be larger in the smaller streams. Since the same general laws apply to rivers whether large or small and whether moving in sand, gravel, or clay, the size of the material forming the channel should not in itself affect channel development." If the physical scales of the model were applied to the flow rate and velocities of the model, it would be physically impossible to move the distorted sediment particles in the model. Therefore, the velocities must be distorted to point of incipient particle mobility. Gaines (2002) states, "This is the point where the bed material begins to mobilize and is identified by the majority of practitioners and researchers as a key condition for similarity of sediment motion between model and prototype."

Due to variance from similitude criteria with increased hydraulic forces, movable bed models generally must utilize a distortion of linear scales. The horizontal scale, or scale of the plan view of the river, deviates from the vertical scale, or scale of the depths within the river channel. The horizontal scale is always smaller than the vertical scale. The result is an exaggeration in all vertical dimensions and slopes in the model. Davinroy (1994) suggests that even in nature, a natural distortion can be found when comparing small streams with large rivers. He states, "The width-depth ratio of a small stream is much less than that of a major river. The forces necessary to move sediment in natural watercourses are generated by the geometric configuration of the channel. Nature compensates for size by "distorting" or creating a smaller width-depth ratio in the stream channel in order that sufficient hydraulic forces are generated to move the bed material. This is why one notices great similarity in the smallest streams as compared to the largest of rivers, regardless of the size of bed materials. This principle is of paramount importance to the theory of movable-bed models." Typical distortion ratios in the micro model usually range between 6.0 and 20.0 while distortion in the large-scale models varied between 1.0 and 10.0.

Because of the deviation from similitude and the distortion of scales that must be applied to a movable bed model, the technique is considered strictly qualitative. River dynamics also dictate that it is impossible to model sediment transport in a quantitative manner. Davinroy (1994) states, "Sediment transport in alluvial rivers and streams is a complex phenomenon that might never be completely reduced to a rational solution. It represents the most extreme degree of unsteady, non-uniform flow, because both the bed and the water surface may undergo continual simultaneous change." The bed of any river cannot reproduce its own exact bed forms and depths. Its general bed forms, or bathymetric trends, may continue to be constant, but it is impossible to achieve any previous condition exactly. Therefore, the goal during calibration of movable bed models is to achieve a resultant bed configuration in the model that is empirically similar to that of the prototype. Only the bathymetric trends of the river are expected to be represented qualitatively within the riverbed of the model. There are no models, physical or numerical, capable of quantitative analyses such as the prediction of exact depths in any given location.

Micro modeling technology adheres to many of the principles developed and utilized by both Reynolds and the traditional large-scale movable bed models. Both the large models and micro models utilize scales very small compared to the actual river being studied. Davinroy (1994) states, "The physical scale and associated forces of the two models are significantly different than the prototype. However, by combining bed materials of low density, large relative particle size, and appropriate time scales, and by skillfully employing the calibration variables of slope, discharge, and sediment input, the models can both be made to transport sediment in a similar fashion as the prototype." Reynolds' only difficulty with modeling on such a small scale was being able to obtain detailed survey information from the bed. The technology to accurately model sediment transport on the micro scale has only recently become available. The more advanced equipment now available on the market has enabled the engineer to use lasers to collect depth data on a micro scale and precisely control small flows of water with magnetic flow meters. Utilizing the smaller scales has saved time and money without sacrificing accuracy.

A recent Corps of Engineers research effort determined that past micro models were able to accurately reproduce the thalweg location and cross sectional area of the riverbed of the actual river. The ability of the micro model to predict bed forms has been substantiated by completed projects that have reacted as the model showed. One of the advantages of a small-scale physical model is the interaction it provides for customers and partners. Complex river concepts can be visually observed and understood by non-engineers. This creates a team building experience with all the interested parties.

## The Bolters Bar Micro Model

The model (Figure 7) used to study the Bolters Bar reach was located at the Corps of Engineers Applied River Engineering Center in St. Louis, Missouri. The model had a horizontal scale (plan view) of 1 to 9600 and a vertical scale (elevation) of 1 to 600. These scales translated into a 16 to 1 distortion ratio. The physical size of the model was 1.8 meters (6 feet) long by 0.9 meters (3 feet) wide. It incorporated almost 18 kilometers (11 miles) of the main river channel as well as each side channel and every river training structure located within the reach. The bed material used to simulate the riverbed of the Mississippi was granular plastic urea with a specific gravity of about 1.4. The study utilized standard micro model methodologies to construct, operate, calibrate, and study design alternatives.

Hydrographic surveys from 1988, 1993, 1995, 1997, and 1998 were used to establish the general trends in the river through the last decade. The analysis showed a river channel that varied from survey to survey but had similar depth and thalweg trends throughout the time period. The model was calibrated to the trends established by this analysis by adjusting variables such as the slope, discharge, sediment volume, hydrograph cycle, and entrance conditions. The model displayed the ability to replicate the bathymetric trends of the prototype, including relative depths and thalweg locations. Most importantly, the model was able to reproduce the shoaling trends evident in the problematic reach of river. Unfortunately, the necessary data required for extensive model verification was not available.

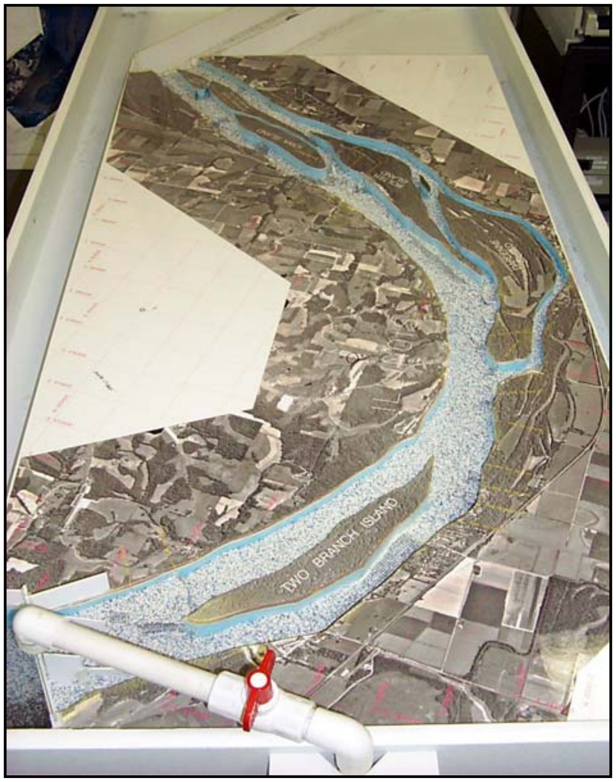

**Figure 7: Bolters Bar Micro Model.**

The plan formulation team utilized the calibrated model to idealize numerous design possibilities for consideration by the design team. The design team, which consisted of engineers and modelers, utilized these concepts to scientifically test different designs in the model to determine their probable effect on the riverbed. Results of these tests were then presented to the plan formulation team for evaluation. This team then reconvened to use these results and the model to formulate additional ideas. The teams proceeded through several of these iterations until a final remedial design was agreed upon.

## REMEDIAL DESIGN

The rehabilitation of a closure structure in Bolter Chute located at UMRM 226.3 was the most pressing need to prevent further deterioration and the loss of additional flow from the main channel. The original structure and banklines were rapidly deteriorating and needed immediate attention. Prior to the model study, river engineers conferred with the partnering agencies to explain the problem and discuss a solution. A remedial measure was then designed to prevent the flows through Bolter Chute from continuing to increase, to reduce flows in the side channel to pre-deterioration levels, and to recapture the eroding bankline near the closure. The design included raising the crown elevation of the structure to an elevation of 1.2 meters (4 feet) above the maximum regulated pool level (MRPL) while leaving a large center notch 61 meters (200 feet) wide with an invert elevation of 2.7 meters (9 feet) below the MRPL. Revetment was added along the banklines upstream and downstream of the structure. This closure was rebuilt in the year 2000 after the completion of the study.

The Corps of Engineers and their team members used the model to conceive and evaluate numerous design alternatives. The model showed that numerous designs utilizing traditional river engineering concepts would greatly reduce dredging in this area. Standard dike fields placed along both banklines would direct the river flows into the center of the channel thereby increasing depths. However, the means of solving traditional dredging issues with standard engineering practices were not acceptable to the environmental agencies and recreational interests. Their interests of protecting and enhancing aquatic habitat while preserving the links to the side channels were not addressed. Therefore, combinations of dikes and chevron structures were evaluated in the model that would also address environmental concerns. Chevrons (shown in Figure 8) are large U-shaped rock structures with blunt-noses rather than pointed, and with the open end facing downstream. These habitat-enhancing structures were considered due to sensitive environmental issues involved in this reach.

Most of the designs tested in the model showed that probable improvements to dredging could be gained from each combination of structure. However, the designs were also evaluated on their effects within each side channel and to the alignment for navigation. Each design’s capacity to create additional aquatic habitat was also considered. These parameters were then weighed with the costs associated with each design to determine the most economical solution to achieve the team’s desired goals.

Several designs were model tested and then evaluated by the team during group meetings. The team was able to agree upon an unconventional design that addressed the needs and concerns of everyone involved. The first part of the design consisted of an extension to an existing longitudinal trail dike. This structure, in combination with the rebuilt closure structure, was designed to minimize the dredging of the upstream point bar near UMRM 227, at the entrance to Bolter Chute.

To reduce dredging in the area where the more costly problem existed, the design consisted of a longitudinal “kicker” dike and four chevron structures (Figure 8). The

365-meter (1,200-foot) long longitudinal “kicker” dike extended off of Bolter Island near UMRM 226. It was angled downstream in a nearly parallel alignment to the river’s flow. It was designed to initiate a push of the flows towards the center of the navigation channel. Downstream of this structure, four chevrons were placed, one after another and about 260 meters (850 feet) apart. All of the structures were built of graded A-Stone (2,270 kilogram or 5,000 pound maximum) and were about 0.6 meters (2 feet) above the MRPL. This slight rise above the water surface makes the structures easily noticeable during normal pool conditions for the safety of the recreational boaters. The chevrons are approximately 75 meters (250 feet) in length, 60 meters (200 feet) wide between the downstream ends of the legs and 185 meters (600 feet) in total length along the perimeter of the structure.

Due to funding constraints, the design was constructed in two phases in the spring and fall of 2002. The work was completed in December 2002; about six months after the first phase began. The final construction cost was nearly $1,500,000 for about 145 million kilograms (160,000 tons) of stone.

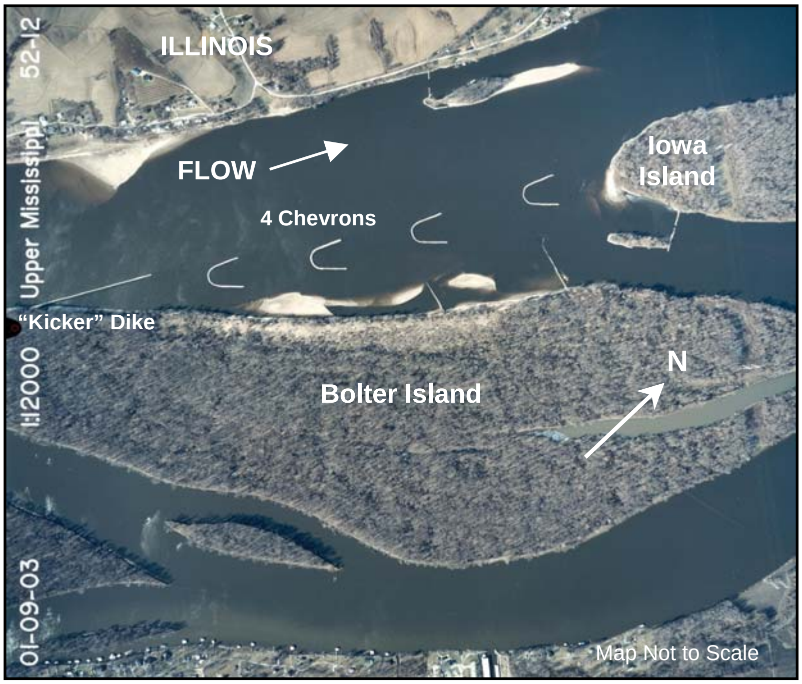


**Figure 8: Aerial Photo of the Completed Remedial Design.**

## RESULTS

The structures have only been in the river for less than two years and the results have been outstanding. Flow distribution measurements have shown an improvement in flow in the main channel and the reach has not required dredging. Although biological monitoring can take years to assess, the results from similar designs give a valid representation of what could be expected to occur in and around these structures.

### Physical Results

Discharge measurements collected near the rebuilt closure structure at UMRM 226.3 revealed that the structure had reestablished the flow distribution at pre-deterioration levels and velocities at the structure returned to normal levels. The rebuilt closure structure along with the extension of the trail dike at the head of Bolter Island appears to have reduced the width of the point bar that extended from the Illinois bankline. This area has not required dredging since the trail extension was completed.

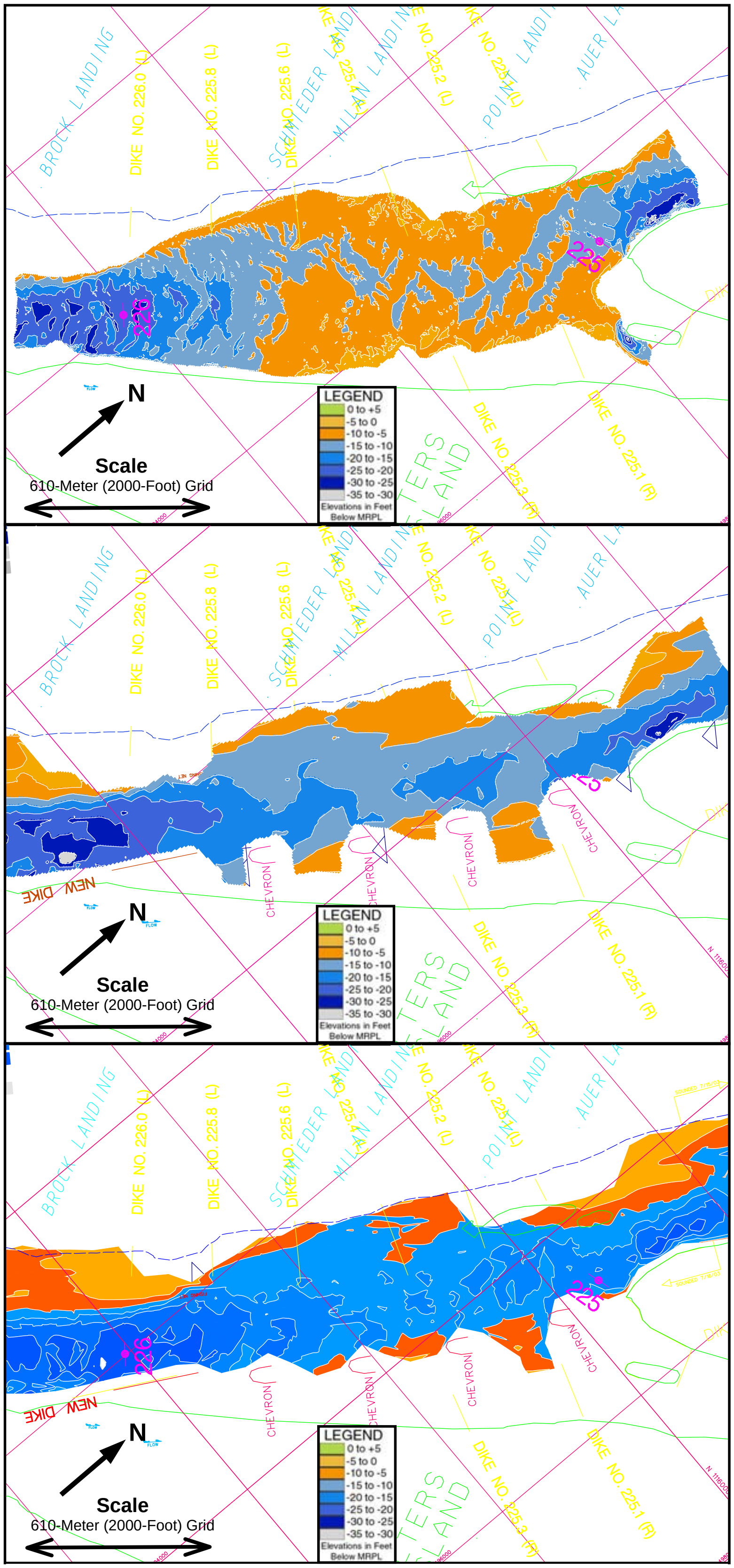


**Figure 9: Hydrographic Surveys Completed Before Construction (Top) and After Construction (Center and Bottom).**

The top of Figure 9 shows a hydrographic survey (shown with 1.5-meter / 5-foot contour increments) of the river from 2001 that shows a channel that required dredging before the remedial measures could be implemented. The orange color-coded contours reveal the areas that did not have navigable depths while the shades of blue represent areas with depths sufficient for navigation. The dredging operation to reopen this channel took 12 days to remove over 230,000 cubic meters (300,000 cubic yards) of material at a cost of almost $500,000.

Shortly after construction was completed in late 2002, the Upper Mississippi River was affected by a period of record low water. A hydrographic survey collected in January 2003 (center of Figure 9) revealed that the minimum depth and width required for navigation had been achieved. The structures had created a self-maintaining navigable channel during low water.

Another hydrographic survey (bottom of Figure 9) was completed during another low water period following a bankfull event. This survey showed even greater depths and additional navigation width had been achieved. In addition to an improved navigation channel, the shallow depths along the Illinois bankline that had been the complaint of homeowners had been improved.

For the first time, two consecutive low water seasons have passed without requiring that this area be dredged. These low water seasons have been two of the driest on record. During this period the record daily low water stage at St. Louis had been surpassed on several occasions. Before implementation of this design, extreme events such as these would have necessitated frequent dredging of the reach. These elongated low water periods with a short duration of high water in between typically activates sediment movement conducive for excessive shoaling in problematic areas. However, with the chevron design in place, depths never before recorded in the reach were established during this extreme low water event.

An improved alignment has allowed towboats to navigate straight down the channel without maneuvering sideways to pass Iowa Island. The River Industry Action Committee has been especially complementary to the effectiveness of the design. RIAC is a collaborative group of towing industry representatives and government officials that monitors river levels and the condition of dangerous reaches for the good of the entire industry. Raymond Hopkins, Chairman of RIAC, reported, "The design has not only resolved one of the Upper Mississippi River's worst reaches for repetitive dredging, it has also drastically improved a dangerous alignment for our downbound tows. All of our concerns in this area were addressed with the implementation of this design. The channel now has sustainable depths and is wide enough that on occasion, tows have been able to overtake one another without incident."

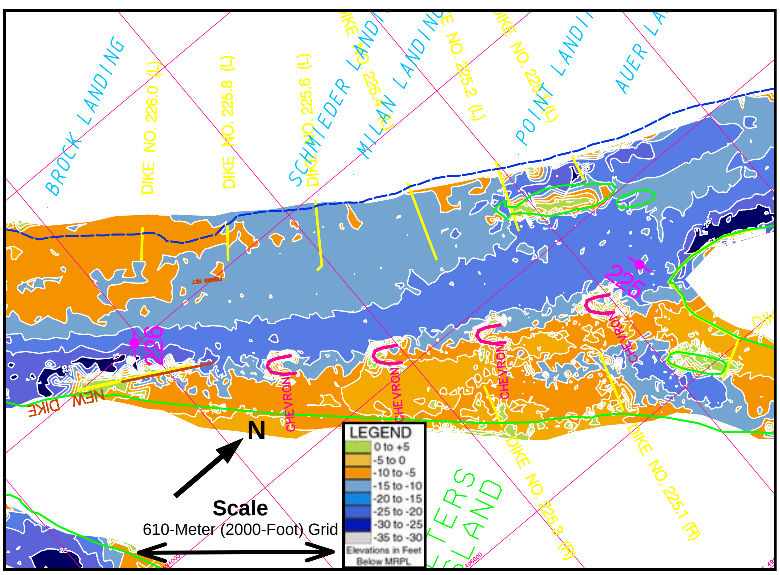


Figure 10: Bathymetry Predicted by the Micro Model.

The results also show that the micro model accurately predicted the design's general effect on the trends of the riverbed. Figure 10 is the bathymetry that the micro model showed would form in the river with the implementation of this design. The model showed that a 120-meter (400-foot) wide continuous channel with depths from 4.5 to 6 meters (15 to 20 feet) would develop through the reach. The hydrographic surveys from the river reveal that a nearly 120-meter (400-foot wide) continuous channel with depths between 4.5 to 6 meters (15 and 20) feet has already developed. It is expected that additional high flow events will eventually scour a continuous channel with depths between 4.5 to 6 meters (15 and 20 feet). Monitoring of the side channel immediately downstream of the structures shows that shoaling has not occurred and depths have been maintained, just as the micro model suggested. As an engineering tool for prediction of bathymetry trends in a continual changing river environment, the predictive accuracy displayed by this model was at an exceptional level.

**Biological Results**

The chevrons built in the Bolters Bar reach are expected to result in the same diverse group of habitat types and species benefits as other chevrons previously built in the Upper Mississippi River. The first preliminary monitoring effort resulted in finding good habitat and a diversity of depth and substrate. A variety of fish including juvenile flathead catfish were found along the outside of the structures. The substrate was diverse with coarser sand and some gravel next to the chevrons and finer sands between the chevrons. Depending on the chevron, the inside depths ranged from about 0.6 to 4.3 meters (2 to 14 feet), with the greatest depths within the upstream chevron and behind the new longitudinal kicker dike (which exceeded 6 meters (20 feet) near the upper end). The insides of the chevrons contained silty mud substrate and it appears that they are being used as a nursery area. Larval catfish and drum were found along with a juvenile mussel and insect larvae from several different families.

The chevron design concept was not originally intended for river training. The structures were conceived for the purpose of protecting a disposal area for dredge material in the river channel. The shape of the structure prevents the downstream movement of dredge material when placed in the downstream "shadow" of the structure. The lower velocities created by the chevron within this shadow prevent the material from moving downstream into another repetitive maintenance dredging area. If the material is placed to an elevation above the water surface, an isolated sand island is created downstream of the structure.

The first three experimental chevrons were constructed in Pool 24 near UMRM 290 in 1993 solely for the purpose of protecting dredge disposal material. Initial monitoring of the chevrons showed that they had immense environmental benefits by creating an abundance and variety of aquatic habitat. Since then, these chevrons as well as three additional chevrons near UMRM 266 have been extensively monitored. A total 51 species of fish and a highly diverse group of macro invertebrates were collected in and around the structures. The eight years of data also

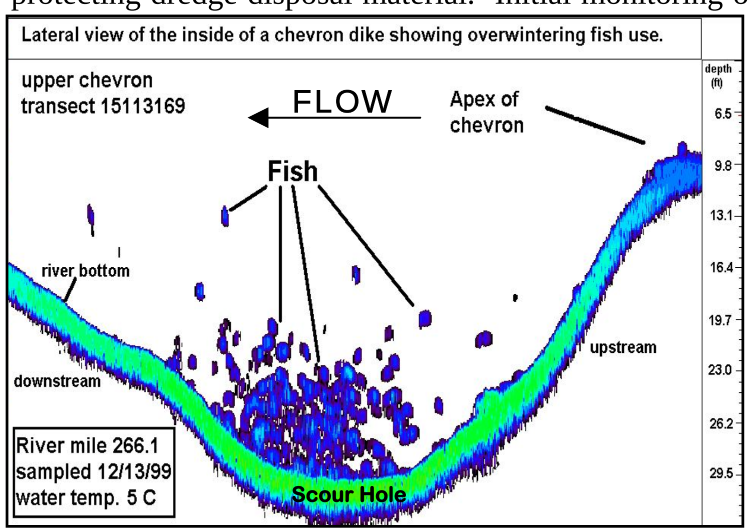

Figure 11: Fish Shown Inside a Chevron.

show a high presence of young of the year and juvenile fishes inside of the structures, which suggests that the structures are being used as nursery habitat. The data also shows that the outside edges of the chevrons are providing excellent habitat for quality-sized catfish. Catch rates inside the chevrons have been more than double the catch rates outside of the structures. Figure 11 shows a high density of fish stacked inside the apex and within the shadow of a chevron. Vegetation colonization, very favorable water quality conditions, and wading bird use of the islands has also been documented.

The physical data collected in and around the structures show extensive depth, velocity, and substrate diversity which usually translates into habitat diversity. The color-coded bathymetry with 0.6-meter / 2-foot increments around the chevrons at UMRM 266 in Figure 12 shows a mosaic of depths. The structures create several different types of river habitat, with variable depth and flow velocities, and with multiple wetted edges or wetted perimeters where plant life can flourish. The diagram in Figure 13 shows that flows, which overtop the structures, create a large scour hole inside of the chevron just downstream of the structure's apex. Downstream of this area, the reshaped material deposits and creates a shallow bar. After the flows drop below the crest of the structure, the scour hole formed at high flow becomes an area of deep slack water. This environment is very conducive to the needs of overwintering fish and provides the ideal conditions for a nursery for juvenile and larval fish. The plant life that establishes along the wetted edges provides good cover and habitat for young fish.

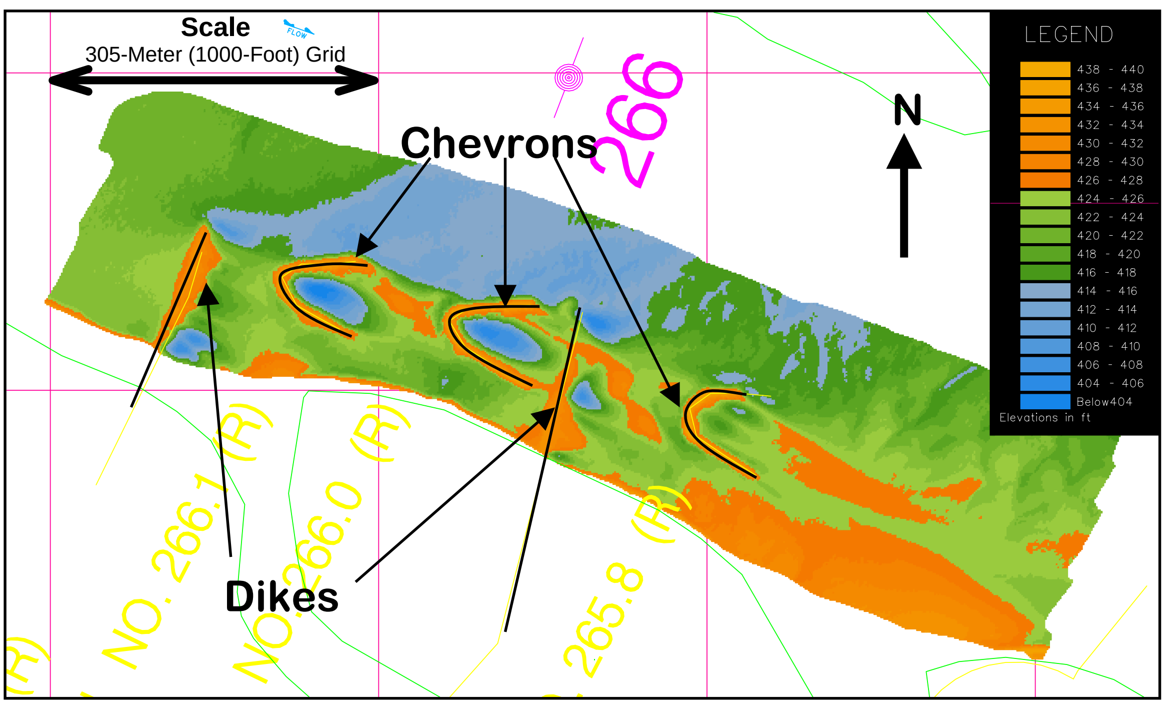


**Figure 12: Bathymetry of a Chevron Field at UMRM 266.**

Additional environmental benefits can be realized if dredge material is placed on the downstream side of the chevron. These exposed sandbars create unique habitats conducive to the nesting needs of the endangered least tern. This bird species utilizes these isolated sand bars as nesting grounds due to the separation from the mainland that creates protection from most land-based predators. It also appears that recreational boaters frequently utilize these bars for their beaches and for overnight camping. It was envisioned that the chevrons at Bolters Bar could also be used to stabilize dredge disposal material if the reach ever required minor dredging.

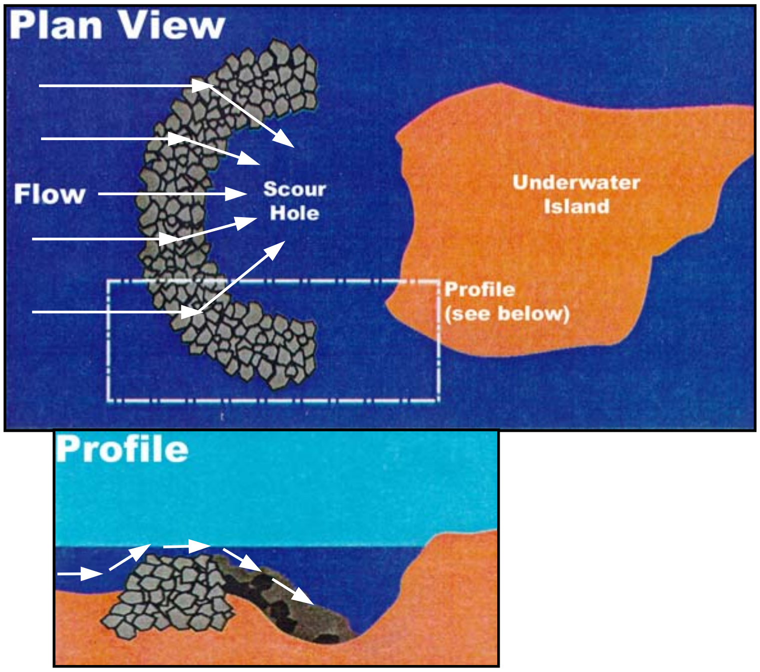


**Figure 13: Chevron Diagram**

## CONCLUSION

It is estimated that this project will pay for itself after just three years. The cost of the dredging this reach in 2001 was approximately $500,000. This results in a cost of nearly $1,500,000 to keep this channel open to navigation for three years. In addition, there are monetary values that result from increased safety and the reduced risk of accidents or groundings. The navigation industry as a whole incurs significant costs from events such as these that close the river to traffic for any amount of time.

The environmental benefits have also been immense but are difficult to quantify. Each chevron provides variable depths and flow velocities, sandbars isolated from the mainland, plunge pools, and increased wetted perimeter. This diversity provides a mosaic of aquatic habitat not readily found along the river such as deep slack water, off-channel nursery areas and aquatic vegetation.

During periodic monitoring inspections, it was noticed that both commercial and recreational fisherman were already using the areas in and around the structures. Close coordination with industry during the design of this project allowed the Corps of Engineers to construct the chevrons without any complaints or concerns from tow pilots. Since construction, the tow pilots have not encountered any navigation problems and have been pleased with the results of the channel improvements. Once the recreational boaters became familiar with the location of the new structures in the river, they also have not expressed any concern over the project.

**Figure 14: Looking Downstream at Chevron Field.**

One of the greatest lessons learned from this project was how a diverse group, with what seemed to be highly conflicting interests, was able to work together to design a solution that would fit the needs of the group as a whole. This project demonstrated that it is possible to remedy a difficult navigation problem in an area where these multiple user groups had a strong desire to protect their own interests. It was important that each team member was intimately involved in the project and with each other from the plan formulation process through the final design and construction. The use of the micro model allowed the engineers, biologists, tow pilots, and environmentalists the unique opportunity to work together to experiment with and design non-traditional river engineering solutions that may not have been considered with other design techniques. This unconventional solution to a troublesome problem has the potential to save the U.S. Government millions of dollars in dredging costs. Unlike many of the navigation related projects of the past, this design ensured the protection of the

**Figure 15: Ski Boat Maneuvering Between Chevrons.**

existing environment while creating additional habitat. The results of this novel project have shown that it is possible to achieve a win-win scenario between navigation interests and the environment.

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